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Generating Topologically Optimized Cellular Structures for Additive Manufacturing

Steve Owen, Josh Robbins, Brett Clark, Tom Voth, Bradley Parks, Ted Blacker

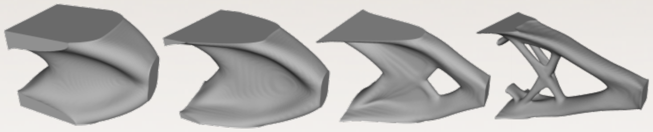
Sandia National Laboratories

Overview

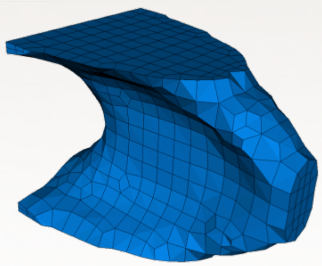
We introduce a new method for generating an STL definition of a lattice structure that can be 3D printed using standard Additive Manufacturing technologies. Using a topology optimization code developed at Sandia, an organic shape designed to accommodate specific loads and boundary conditions is first meshed using the Sculpt application. The hex elements produced are used as the basis for generating a lattice structure that is exported as an STL file. Following 3D printing, the result is a reduced-weight component using minimal material to meet structural strength criteria.

Topology Optimization

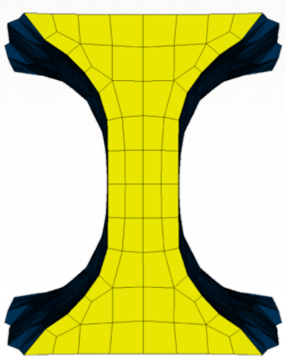
Based on various load conditions and material properties, an optimized shape is produced.

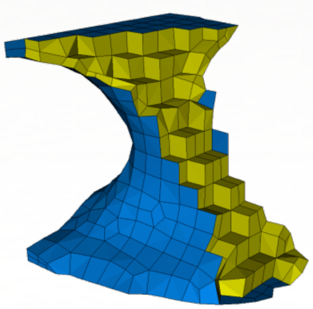


Sculpt Hex Meshing



From the STL boundary representation produced from the topology optimization, Sandia's Sculpt code is used to generate an all-hex mesh at a user defined resolution.





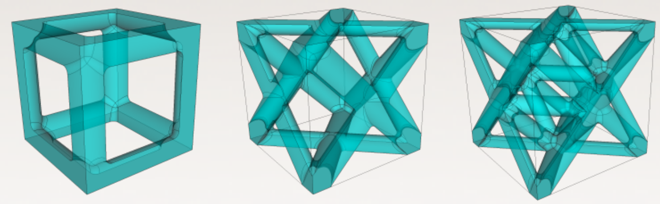
Paper reference:

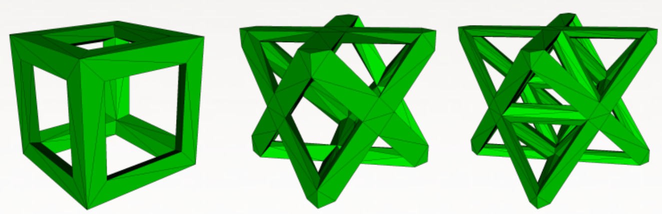
J. Robbins, S.J. Owen, B.W. Clark, T.E. Voth, "An efficient and scalable approach for generating topologically optimized cellular structures for additive manufacturing, Additive Manufacturing, Available online 21 July 2016 http://dx.doi.org/10.1016/j.addma.2016.06.013

Lattice Templates

A template geometry to be used in each hex of the mesh is selected. Templates are defined from Boolean operations on analytic cylinders configured to optimize strength and density characteristics. Templates are required to be super-symmetric, where rotations in u, v, or w directions yield identical results. To reduce memory requirements, analytic surfaces are reduced to a minimal set of triangles for each configuration.

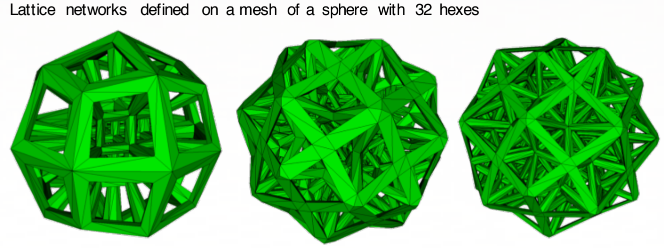
Hexahedron | Octahedron | Tetrahedron





96 Triangles | 232 Triangles | 468 Triangles

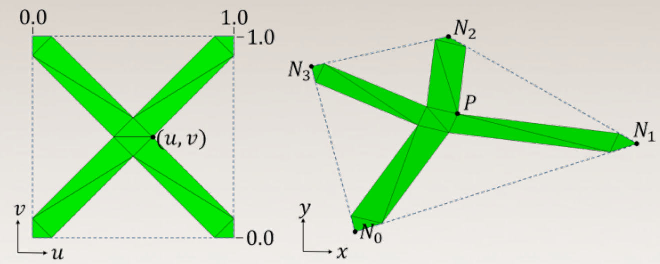
Lattice networks defined on a mesh of a sphere with 32 hexes



1728 Triangles | 5072 Triangles | 12,624 Triangles

Template Mapping

The triangles in the selected template are copied and mapped into each hex of the finite element mesh generated with Sculpt. The template, defined on a unit cube is mapped to a general 3D space element using the following.



Transfinite interpolation is used to map a given STL triangle vertex on the unit cube with coordinate u,v,w, to a 3D x,y,z coordinate. Edge and face coordinates can be computed as follows:

$$E_0 = N_0 + u(N_1 - N_0)$$
$$E_1 = N_1 + v(N_2 - N_1)$$
$$E_2 = N_3 + u(N_2 - N_3)$$
$$E_3 = N_0 + v(N_3 - N_0)$$
$$P_{2D} = \frac{E_3 + u(E_1 - E_3) + E_0 + v(E_2 - E_0)}{2}$$

With the 3D coordinate computed as a linear combination of the three coordinate directions.

$$P_u = P_{umin} + u(P_{umax} - P_{umin})$$
$$P_v = P_{vmin} + v(P_{vmax} - P_{vmin})$$
$$P_w = P_{wmin} + w(P_{wmax} - P_{wmin})$$
$$P_{3D} = \frac{P_u + P_v + P_w}{3}$$

Triangles on the faces of the template are only mapped to the 3D hex element if it lies on the exterior boundary of the model. This allows for a single continuous water-tight volume composed of STL facets.

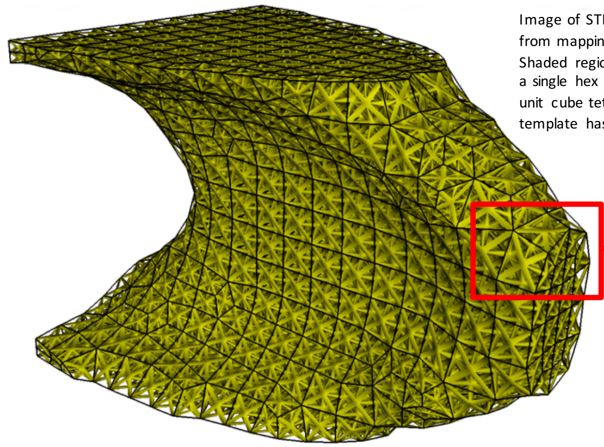
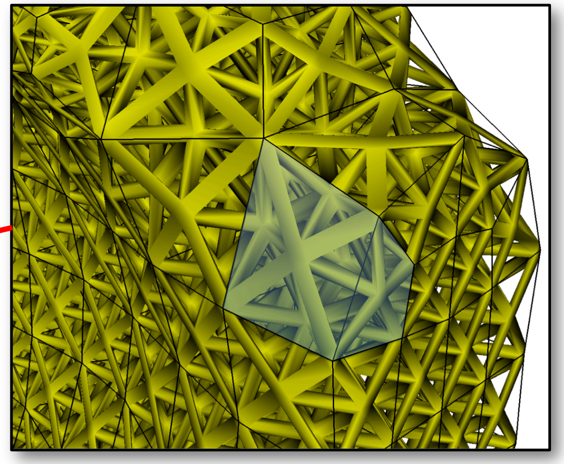
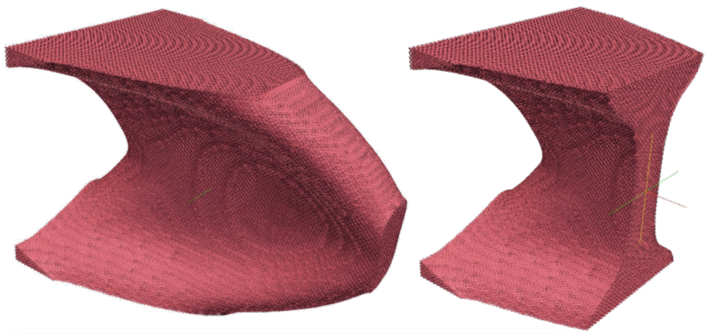


Image of STL model produced from mapping procedure. Shaded region on inset shows a single hex element where a unit cube tetrahedron template has been mapped.





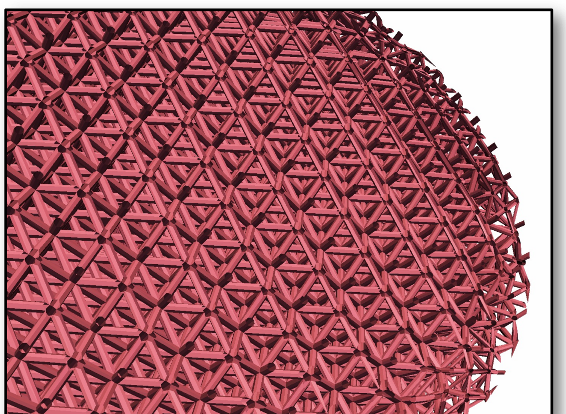
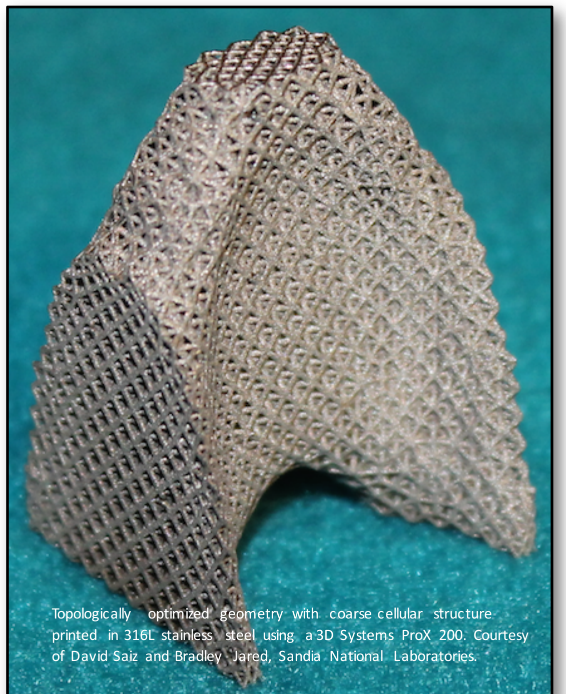


Image of STL model of a high resolution tetrahedron lattice structure with over 26 million triangles

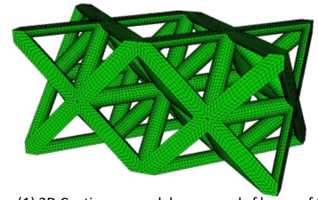
3D Printing



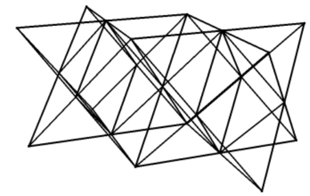
Topologically optimized geometry with coarse cellular structure printed in 316L stainless steel using a 3D Systems ProX 200. Courtesy of David Saiz and Bradley Jared, Sandia National Laboratories.

Validation Modeling

To computationally validate the strength of lattice structures, two different finite element approximations were used: (1) a continuum model composed of 3D cylinders and conformally meshed with hexahedral elements, and (2) a beam element approximation, where each cylinder is approximated by a single beam element.

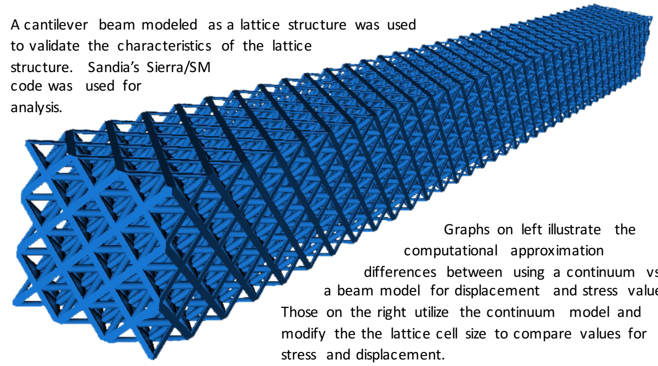


(1) 3D Continuum model composed of hexes of two lattice templates of the tetrahedron configuration

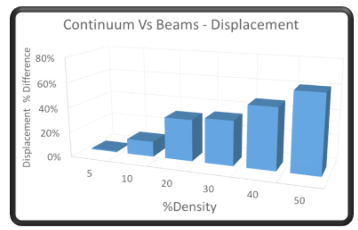


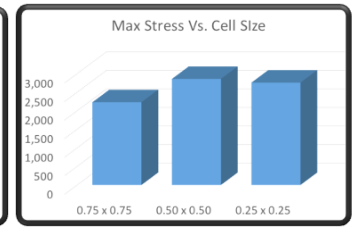
(2) 3D beam model composed of beams of the same tetrahedron configuration.

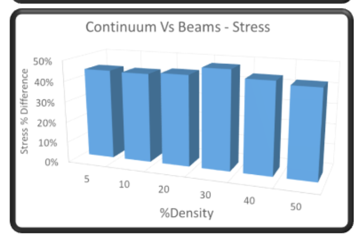
A cantilever beam modeled as a lattice structure was used to validate the characteristics of the lattice structure. Sandia's Sierra/SM code was used for analysis.

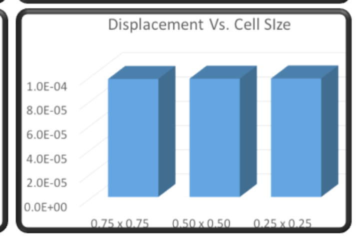


Graphs on left illustrate the computational approximation differences between using a continuum vs. a beam model for displacement and stress values. Those on the right utilize the continuum model and modify the the lattice cell size to compare values for stress and displacement.









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NNSA National Nuclear Security Administration

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